VEHICLE CONTROL SYSTEM AND VEHICLE CONTROL METHOD

FIELD OF THE INVENTION

[0001] This invention relates to a vehicle control, and in particular relates to the control of a vehicle provided with a generator and a vehicle drive motor.

BACKGROUND OF THE INVENTION

[0002] In recent years, hybrid vehicles (HEV) comprising an engine, motor and generator have been commercialized. HEV can be broadly classified into series HEV and parallel HEV. In both cases, all or part of the power of the engine is converted to electrical energy by the generator. Part of this electrical energy is supplied directly to the motor, and the excess electrical energy is stored in a battery. Electrical energy is supplied to the motor not only from the generator but also from this battery. The supplied electrical energy is converted to kinetic energy by the motor, and drives the vehicle.

[0003] When the energy produced by the engine passes through the generator, battery and motor, losses occur, and these losses are not necessarily small. Consequently, the parallel HEV wherein a mechanism is provided to drive the vehicle directly under the engine output and suppress these losses, has become the most popular form of hybrid vehicle.

[0004] However, if the energy consumed by the motor could be directly supplied by the generator without insufficiency or excess, the losses occurring when the battery is charged or discharged would be largely reduced, and the

efficiency of even a series HEV might be improved. In JP-A-H11-146503 published by the Japanese Patent Office in 1999, a control method (referred to hereafter as synchronous power generation control) wherein the power consumed by the motor is generated by the generator without insufficiency or excess, in order to reduce the losses when the battery is charged or discharged.

SUMMARY OF THE INVENTION

[0005] However, in an HEV which performs this type of synchronous power generation control, battery charging and discharging may be performed intentionally due to the following reason.

[0006] Reason 1: Even if it is attempted to perform synchronous power generation control, it is impossible to completely eliminate excesses or insufficiencies, so the battery state of charge (SOC) must be feedback-controlled to an optimum value.

[0007] Reason 2: The synchronous power generation control will not always give the optimum fuel cost-performance under all running conditions. It may occur that under specific running conditions, synchronous power generation control may be interrupted and the battery is used.

[0008] Therefore, the following problem occurs when battery charging/discharging is performed intentionally while performing synchronous power generation control. Specifically, if the power generated is made less than the power required by the motor, the deficiency must be made up by power from the battery. However, the power which can be

extracted from the battery and output to the motor varies according to the voltage which is applied to the motor, and if the generated power is reduced without considering the power which can be output, the power which can actually be output (discharged) from the battery will be less than expected, and it may not be possible to supply the motor power required by the driver.

[0009] It is therefore an object of this invention to supply a motor power required by the driver without being affected by a battery charge state, when battery charging/discharging is performed intentionally while performing synchronous power generation control.

[0010] In order to achieve above object, this invention provides a control system for a vehicle, comprising a generating device, a battery, a motor electrically connected to the generating device and battery, which drives the vehicle, and a controller which functions to determine a running condition of the vehicle, compute a target motor power, which is a target value of the power of the motor, based on the vehicle running condition, compute an available output from the battery to the motor based on the target motor power, compute a target generated power, which is a target value of the power generated by the generating device, based on the available battery output and target motor power, and control the generating device based on the target generated power.

[0011] The details as well as other features and advantages of this invention are set forth in the remainder of the specification and are shown in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Fig. 1 is a schematic view of a vehicle control system according to this invention.

[0013] Fig. 2 is a control block diagram of a general controller.

[0014] Fig. 3 is a required voltage table.

[0015] Fig. 4 is a map of the power which can be output by a battery. Fig. 4(a) shows characteristics when the battery temperature is 25°C, Fig. 4(b) shows characteristics when the battery temperature is 0°C, and Fig. 4(c) shows characteristics when the battery to which is -10°C.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0016] Referring to Fig. 1 of the drawings, the drive force of an engine 1 is transmitted to drive wheels, not shown, via a continuously variable transmission (CVT) 3. The CVT 3 comprises a motor-generator 4 and 5, the motor-generator 4 on the input side being connected to an output shaft 2 of the engine 1, and the motor-generator 5 on the output side being connected to a drive shaft 7. The motor-generator 4 mainly functions as a generator, and the motor-generator 5 mainly functions as a motor driven by the power generated by the motor-generator 3. Hereafter, the motor-generator 4 will be referred to as a generator, and the motor-generator 5 will be referred to as a motor.

[0017] The generator 4 and motor 5 comprise alternating current devices such as permanent magnet alternating current synchronous motors, and are connected respectively to an inverter 8. The rotation speeds of the

generator 4 and motor 5 are controlled according to the drive frequency of the inverter 8. The ratio of drive frequencies of the inverter 8 is the speed ratio (ratio of output rotation speed to input rotation speed) of the CVT 3.

[0018] A generator rotation speed *Ni* from a generator rotation speed sensor (input shaft rotation speed sensor of the CVT 3) 21, and a motor rotation speed *No* from a motor rotation speed sensor (output shaft rotation speed sensor of the CVT 3) 22, are input to a transmission controller 11. The transmission controller 11 controls the drive frequency of the inverter 8 so that a target generator rotation speed *tNi* and target motor torque *tTo* computed by a general controller 13 are obtained.

[0019] A clutch 6 is interposed between the generator 4 and motor 5, and the input shaft of the generator 4 and output shaft of the motor 5 can be connected by engaging the clutch 6. The clutch 6 is controlled according to a command from an engine controller 12. For example, when the input shaft rotation speed and output shaft rotation speed of the CVT 3 are equal, the clutch 6 is engaged, and the drive force of the engine 1 is directly transmitted to the drive wheels so as to improve the fuel cost-performance of the vehicle by suppressing the losses in the generator 4 and motor 5.

[0020] The engine controller 12 controls an opening *TVO* of an electronic control throttle 14 so that the target engine torque *tTe* computed by the general controller 13 is obtained. An intake air amount according to the throttle opening flows into the engine 1. A flowrate *Qa* of the intake air is measured by an air flow meter 23 installed upstream of the electronic control throttle 14. In the engine controller 12, fuel injection control is performed by fuel injectors 15 and ignition timing control is performed by spark plugs 16

based on the air flow rate *Qa* and the engine rotation speed from a crank angle sensor 24.

[0021] An accelerator depression amount *APO* from an accelerator depression sensor 25 and a temperature *Tmpb* of the battery 27 from a temperature sensor 26 are input to the general controller 13. Based on these signals, the generator rotation speed *Ni* and motor rotation speed *No* obtained via the transmission controller 11, the general controller 13 computes the target motor torque *tTo* supplied to the motor 5 and target generator rotation speed *tNi* supplied to the generator 4 so that synchronous power generation takes place.

[0022] Synchronous power generation control has the following basic features.

(1) A target motor power *tPo00* which is the target value of the power of the motor 5, is computed based on vehicle conditions (in this embodiment, the accelerator depression amount *APO* and vehicle speed *VSP*),

(2) The motor 5 is controlled based on a target generated power *tPg*,

(3) The target generated power *tPg* which is the target value of the power generated by the generator 4 is computed based on the target motor power *tPo00*,

(4) The generator 4 is controlled based on this target generated power *tPg*.

[0023] Further, in this embodiment,

(5) An available battery output *Pblim* is computed based on the target motor power *tPo00*, and

(6) The target generated power *tPg* is computed taking account of the available battery output *Pblim*.

[0024] The synchronous power generation control performed by the general

controller 13 will now be described in detail referring to the control block diagram of Fig. 2.

[0025] In a block B1, a target drive force *tFd0* [N] is computed based on the accelerator depression amount *APO* [deg] and vehicle speed *VSP* [km/h]. Specifically, the target drive force *tFd0* is computed by looking up a target drive force map based on *APO* and *VSP*. The accelerator depression amount *APO* is detected by the accelerator depression sensor 25. The vehicle speed *VSP* is detected by multiplying the motor rotation speed *No* [rpm] detected by the motor rotation speed sensor 22, by a constant *G1*. If the radius of the drive wheels of the vehicle is *r* [m] and the gear ratio from the output shaft of the motor 5 to the drive shaft is *R*, the constant *G1* is a value calculated by the following equation:

$$G1 = 2 \times \pi \times r \times 60 \ / \ (R \times 1000)$$

[0026] In a block B2, a target motor power *tPo00* [W] is computed by multiplying the target drive force *tFd0* [N] by the vehicle speed *VSP* [m/s] so that the target drive force *tFd0* is generated by the motor 5. The *VSP* used in the computation must be in units of [m/s], so the *VSP* in [m/s] units is computed by multiplying the motor rotation speed *No* [rpm] by a constant *G2*. The constant *G2* is a value calculated by the following equation:

$$G2 = 2 \times \pi \times r \ / \ (R \times 60).$$

[0027] In a block B3, filter processing is performed on the target motor power *tPo00* [W]. This filter processing is performed in order to lower the apparent control response speed of the motor 5.

[0028] In a block B4, the target motor torque *tTo* [Nm] is computed by dividing the target motor power *tPo0* [W] after filter processing, by the motor rotation

speed No [rad/s]. The units of the motor rotation speed No used here are [rad/s], so No in units of [rad/s] is computed by multiplying the motor rotation speed No [rpm] by a constant $G3$. The constant $G3$ is a value calculated by the following equation:

$$G3 = 2 \times \pi / 60$$

[0029] The computed target motor torque tTo is sent to the transmission controller 11. The transmission controller 11 controls the torque of the motor 5 via the inverter 8 based on this target motor torque tTo.

[0030] In a block B5, an efficiency $EFFm$ of the motor 5 is computed based on the aforesaid target motor torque tTo [Nm] and motor rotation speed No [rpm].

[0031] In a block B6, a motor consumption power $tPo01$ [W] is computed by dividing the target motor torque $tPo00$ [W] by this motor efficiency $EFFm$. In this embodiment, synchronous power generation control is performed and the power consumed by the motor 5 is basically generated by the generator 4 without excess or insufficiency, so the motor consumption power $tPo01$ during synchronous power generation is the basic value of the target generated power of the generator 4.

[0032] In a block B7, a value obtained by subtracting a battery output tPb [W] (described in detail later) from this motor consumption power $tPo01$ [W], is computed as the target generated power tPg [W]. The battery output tPb is a positive value when power is output from the battery 27 (discharge), and is a negative value when power is input to the battery 27 (charge).

[0033] In a block B8, an efficiency $EFFg$ of the generator 4 is computed based on the generator rotation speed Ni [rpm] and the immediately preceding value of

the target generator torque *tNe* [Nm] (supplied by a block B14 which outputs a value computed on the immediately preceding occasion). In a block B9, a generator consumption power *tPe* [W] is computed by dividing the target generated power *tPg* [W] by this generator efficiency *EFFg*. The generator 4 is driven by the engine 1, so the generator consumption power *tPe* represents the target engine power. As the engine 1 and generator 4 are directly connected, the generator rotation speed *Ni* is equal to the engine rotation speed.

[0034] In a block B10, a second target drive force *tFd* [N] is computed by dividing the target engine output *tPe* [W] by the vehicle speed *VSP* [m/s].

[0035] In a block B11, a target generator rotation speed *tNi0* [rpm] is computed based on the second target drive force *tFd* [N] and vehicle speed *VSP* [km/h]. This computation is performed for example by looking up an output distribution map.

[0036] In a block B12, filter processing is performed on the target generator rotation speed *tNi0* [rpm]. This filter processing is performed in order to lower the apparent control response speed of the generator 4, and is identical to the filter processing of the block B3.

[0037] The target generator rotation speed *tNi* [rpm] after filter processing is sent to the transmission controller 11. The transmission controller 11 controls the rotation speed of the generator 4 via the inverter 8 based on the target generator rotation speed *tNi*.

[0038] In a block B13, the target engine torque *tTe* [Nm] is computed by dividing the target engine power *tPe* [W] by the generator rotation speed *Ni* [rad/s]. The units of the generator rotation speed *Ni* used in this computation are

[rad/s], so *Ni* in units of [rad/s] is computed by multiplying the generator rotation speed *Ni* [rpm] by the constant *G3*.

[0039] The target engine torque *tTe* is sent to the engine controller 12. In the engine controller 12, the engine torque is controlled based on the target engine torque *tTe*. Specifically, the opening of the electronic control throttle 14 is controlled to increase or decrease the intake air amount of the engine 1. In general, the actual engine torque follows the throttle opening control with a predetermined delay, so the filter processing of the block B3 or B12 is performed to synchronize the phase of the control of the motor 5 and generator 4 with this engine response delay.

[0040] In the blocks B15, B16, the available battery output *Pblim*, which is the power which can be output from the battery 27 to the motor 5, is computed based on the target motor power *tPo00*. First, in the block B15, a required voltage *V* [V] which is applied to the motor 5 is computed based on the target motor power *tPo00* [W]. The computation of this required voltage is performed by looking up a required voltage table shown in Fig. 3 based on the target motor power *tPo00*.

[0041] In the block B16, the available battery output *Pblim* [W] is computed based on the required voltage *V* [V], battery state of charge *SOC* [%] and battery temperature *Tmpb* [°C]. This computation has three parameters, so two maps are first selected from Fig. 4 (a)-(c) according to the battery temperature *Tmpb*, and the look-up values of the selected maps are calculated based on the required voltage *V* and battery state of charge *SOC*. The available battery output *Pblim* is then calculated by linear interpolating between the values obtained by looking at these maps.

[0042] The reason why the available battery output *Pblim* is computed taking account not only of the required voltage *V* but also of the battery state of charge *SOC* and battery temperature *Tmpb*, is that the battery state of charge *SOC* or battery temperature *Tmpb* affects the available battery output *Pblim*. For example, in Fig. 4(a) which shows the state when the battery temperature *Tmpb* is 25°C, the value of the available battery output *Pblim* decreases the smaller the battery state of charge *SOC* becomes for the same required voltage *V*. The available battery output *Pblim* decreases the lower the battery temperature *Tmpb* becomes (Fig. 4(a)→Fig. 4(b)→Fig. 4(c)) for the same voltage *V*, and the same battery state of charge *SOC*. The battery state of charge *SOC* is detected by an SOC sensor 28. Specifically, the SOC sensor 28 detects the *SOC* based on the current flowing in and out of the battery 27 and the terminal voltage at that time. *Tmpb* is detected by a temperature sensor 26.

[0043] In block B17, a target battery output *tPb0* [W] is computed to feedback control the battery state of charge *SOC* [%] to a target battery state of charge *tSOC* [%]. For example, if linear control is used as the feedback control, the target battery output *tPb0* is computed by the following equation using a proportional gain *Kp*.

$$tPb0 = Kp \times (SOC - tSOC)$$

[0044] The target battery output *tPb0* obtained from this equation is a positive value (discharge) when the actual *SOC* is higher than *tSOC*, and is a negative value (charge) when the actual *SOC* is lower than *tSOC*.

[0045] In a block B18, the target battery output *tPb0* [W] and available battery output *Pblim* [W] are compared, and the smaller is selected as the battery

output *tPb* [W].

[0046] Next, the operation of this embodiment will be described.

[0047] In this embodiment, the power consumed by the motor 5 is generated by the generator 4 without excess or insufficiency (synchronous power generation control). If the synchronous power generation control were ideal, the fluctuation in the battery state of charge *SOC* would be zero.

[0048] However, in practice, it is difficult to make the power consumption of the motor 5 coincide exactly with the power generated by the generator 4, so it may occur that the *SOC* gradually moves away from the optimum value (*tSOC*) as the vehicle continues running. Therefore, the *SOC* is feedback controlled (B17, B18).

[0049] For example, when the actual *SOC* is larger than the optimum value (target value), the power generated by the generator 4 is made less than the power consumed by the motor 5, and this difference of power is discharged from the battery 27 so that the *SOC* approaches the optimum value. Hence, although synchronous power generation control is basically performed, power may be extracted from the battery 27 in some cases.

[0050] The outputtable power by the battery 27 (available battery output), varies according to the voltage applied to the motor 5. For example, even if the *SOC* and temperature of the battery 27 are the same, when the voltage applied to the motor 5 is high (when the motor 5 generates high power), the available battery output is less than when the voltage applied to the motor 5 is low. Ignoring this fact, if the target generated power *tPg* were determined by subtracting the battery output determined to perform SOC feedback control from the motor power consumption *tPo01*, the power would be

insufficient if the available battery output at that time was less than the battery output, and the motor power required by the driver would not be obtained.

[0051] To deal with this, in this embodiment, the available battery output *Pblim* is computed (predicted) by the blocks B15, B16, and a final battery output *tPb* is determined by limiting the target battery output *tPb0* for SOC feedback control by the computed available battery output *Pblim.* Therefore, the battery output *tPb* is not set larger than the available battery output *Pblim,* the aforesaid power insufficiency is avoided, and the motor power required by the driver is always obtained.

[0052] In this embodiment, SOC feedback control was given as an example of intentional battery discharge control, but the invention is not limited to this case, and may be applied also when all the power of the battery 27 is used to run the vehicle.

[0053] Further, the case was described where the generating device comprised the engine 1 and generator 4, but the invention is not limited to this case, and may be applied also to a vehicle using another type of generating device (e.g., a fuel cell).

[0054] The entire contents of Japanese Patent Application P2001-73635 (filed March 15, 2001) are incorporated herein by reference.

[0055] Although the invention has been described above by reference to a certain embodiment of the invention, the invention is not limited to the embodiment described above. Modifications and variations of the embodiments described above will occur to those skilled in the art, in the light of the above teachings. The scope of the invention is defined with

reference to the following claims.